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FEDERAL COMMUNICATIONS COMMISSION
OFFICE OF THE SECRETARY

ICO

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July 24, 1998

**Via Hand Delivery**

Ms. Magalie Roman Salas
Secretary
Federal Communications Commission
1919 M Street, NW – Room 222
Washington, DC 20554

Re: EX PARTE
ET Docket No. 95-18

Dear Ms. Salas:

Mary Frost, Regional General Manager, ICO Global Communications, North America ("ICO"), Larry Darby, Senior Advisor to CompassRose International, Inc., and the undersigned met July 21, 1998 with Ari Fitzgerald, Legal Advisor to Chairman William E. Kennard, to discuss ICO's regulatory status at the FCC.

Larry Darby discussed the economic impact of proposed relocation costs on global satellite systems and presented the attached paper and outline on the same. ICO provided an update on the commercial progress of its global satellite systems and discussed regulatory issues related thereto. ICO also presented the attached papers and filings addressing other relevant issues.

Two copies of this letter have been submitted to the Secretary of the Commission for inclusion in the public record, as required by Section 1.1206(b)(2) of the Commission's rules.

Very truly yours,

Francis D.R. Coleman
Director of Regulatory Affairs, North America
ICO Global Communications Services Inc.

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Attachments
cc: Ari Fitzgerald
Mary Frost
Larry Darby

A Member of the
ICO Global Communications
Group of Companies

Talking Points for Mr. Ari Fitzgerald
Larry F. Darby – July 21, 1998

My perspective on satellites is from the point of view of an economist, a former "regulator" and an investment banker. My basic view is that technological forces drive and enable markets, while regulatory actions constrain and shape them. More specifically, in the global satellite sphere, FCC regulations can and do create, constrain and redistribute both costs and value in the market place while also setting precedents for other regulators worldwide. The result is that FCC regulations will influence costs and incentives for investors and, more generally, the outcome of both investment and competitive processes.

A. **Some Basic Satellite Market Economics**

1. Supply Side
   - Threshold plant costs are large, fixed, sunk and irreversible
   - Network and plant indivisibility
     - a. lack of scalability
     - b. "all or nothing" system investment
   - Cost uncertainty – global spectrum costs

2. Demand Side
   - User externalities – user value depends on number of users hooked up
   - Revenue is "jointly" produced by users in different countries
   - Uncertainty – licenses/operating partners in multiple jurisdictions

B. **Financial Implications**

- Long market gestation and time to "break even"
- Substantial operating leverage
- Uncertain costs and revenues – cost and revenue structure mean market risk
- "Asynchronous" cash flow – front loaded costs and deferred revenues

C. **Regulatory Implications**

- Minimize delay
- Minimize regulatory uncertainty
- Minimize regulatory costs
- Recognize "demonstration" effect of FCC actions on the rest of the world

D. **Conclusion**

Some of these characteristics may be present to a limited extent in domestic terrestrial systems, but are far more pervasive and intense in the case of global satellites. My conclusion is that the economic and world regulatory structure of this market is sufficiently different to warrant "special" regulatory treatment derived from recognition and analysis of the differences.

# Economic Policy Issues Related to Global Satellites

*Presentation to*

*Federal Communications Commission*

Larry F. Darby

Senior Advisor to CompassRose International, Inc.

July 20, 1998

Thank you for taking the time to allow me to discuss some economic issues growing out of global satellite proceedings currently before the Commission.

# Overview of Presentation

- Policy goals
- Core of the economic analysis
- Global implications of Commission action
- Capital market implications
- Economic perspectives on relocation policy
- Conclusions

*CompassRose International, Inc.* July 20, 1998 **Slide 2**

I will talk in the next few minutes about a) the implications in capital markets, as well as the ability of firms to raise risk capital and b) the broader global economic implications of the timing and content of pending Commission decisions involving the ICO system of satellites. I will begin with a statement of US goals that drive FCC policies toward global satellites and conclude that: a) any relocation costs imposed on ICO will be magnified globally, b) the prospects of such costs will increase risk and hamper the ability of the company to access capital markets, c) domestic terrestrial precedents with regard to relocation costs have very limited precedential value, and d) FCC rulings here may well discriminate against competitive carriers' offering like services and will thereby bias consumer choice and undermine ICO's opportunity to succeed in the marketplace.

To support these conclusions, I will review some key political economic features of global satellite systems that distinguish them from the domestic, terrestrial systems that the Commission deals with in the main.

I have long been told, as you have, that satellites are different. I am here to discuss some of the particular ways that they differ economically -- presence of externalities, large transactions costs, indivisible and irreversible sunk costs -- and ways that they differ geopolitically. In particular, I want to emphasize the risk exposure that global systems face; namely, foreign discrimination by regulators favoring domestic champions or driven by other motives.

## Satellite Policy Goals

- Encourage global satellite development
- Encourage satellite systems/services competition
- Encourage open access to global markets
- Promote investment; risk taking; innovation
- US leadership in commercialization of space
  - Technology
  - Exports of satellite products and services
- Balance with other public interest goals

CompassRose International, Inc. July 20, 1998 Slide 3

The United States has for some time set forth and pursued affirmative policies that encourage the development of satellite technology -- first for military purposes, then for general communications purposes and more recently because the construction of satellite systems and the provision of such services creates income, wealth and jobs for US firms and households. US firms -- providing space and terrestrial hardware, launch activities, software, R&D, consulting, insurance and other associated outputs -- garner the lion's share of direct and stimulated economic activity from the construction of global satellite systems. We have a distinct comparative advantage in this sector and, historically, our policy has been to leverage such an advantage.

The government has also pursued policies of encouraging competition -- unfettered competition with no favorites -- not solely as a means of directly serving the best interests of US consumers, but also as a means of encouraging open access to world markets for US satellite systems and other U.S. terrestrial telecommunications firms.

US authorities have historically recognized the intense capital nature of satellite systems and the fact that investment and innovation in such systems have direct effects, as well as important spillovers into other sectors of the economy. The goal has been, with few departures in practice, to stimulate investment, encourage risk taking and create a climate congenial to innovation in this leading sector. US leadership in the commercialization of space has been one of the industrial success stories in the last quarter of the 20th century. The policies leading to that success have been clearly defined. And, they have worked.

While these goals have been been balanced with other public interest goals, they have not been sacrificed to other pursuits.

# Core of the Analysis

- Four parts of the economic analysis:
  1. Global satellite systems differ in ways with significant policy implications
  2. US policies have significant externalities
     - External costs and external benefits
     - ROW will "follow" US leadership
  3. Relocation burdens will
     - Increase cost and prices
     - Increase uncertainty
     - Invite ROW to discriminate against US firms
  4. Relocation rules impact other policy goals

CompassRose International, Inc. July 20, 1998 Slide 4

My analysis is derived in the main from four basic premises, each of which is the result of significant amounts of prior analysis. Taken together, they provide a reasoned basis for evaluating the public's interest in these proceedings.

Satellites are different from terrestrial systems. Pardon me for stating what might seem obvious. And further, global systems are different from domestic ones. Pardon again, but it is important to plumb the implications of the differences. They are not trivial.

What the FCC does in these proceedings will have "demonstration effects" abroad within countries that are looking for ways and rationales to (1) finesse open market access (2) generate revenue for domestic purposes, (3) discriminate against US firms and/or protect domestic favorites. The rest of the world will take direction from US initiatives, but will in all cases construe them in ways beyond US control and, perhaps, outside the bounds of US private and public interests.

This demonstration effect is especially important in the context of how the Commission regards the burdens of imposing relocation costs on satellite entrants. The immediate effect is to increase costs, uncertainty and prices -- all of which will ultimately be borne by consumers. While these effects are shared in common with outcomes in a purely terrestrial context, the major difference is that the rest of the world will be invited to use the precedent and to apply it in ways that will discriminate against US firms. Differential treatment in the US of satellite carriers with non-US owners will be regarded in some jurisdictions as license to do likewise to US carriers.

Assignment of these relocation costs will look like a tax to the rest of the world. Moreover, its imposition on ICO but not on other satellite carriers providing substitute services is at odds with the Commission's policies toward new competitive entrants. Assignment of relocation burdens may also discourage innovation and pursuit of new technologies -- satellite and otherwise -- if the precedent is replicated further here and abroad.

# Political Economy of Global Satellites

- Multiple political jurisdictions
- Special cost characteristics
  - High fixed costs and operating leverage
  - Costs shared with other countries
  - Enormous "transactions" costs
  - Space segment/ "system" costs are indivisible
    - Contrasts sharply with terrestrial systems
- Special demand characteristics
  - Enormous consumption "externalities"
  - Value to US increases with number of nations/consumers addressed

CompassRose International, Inc. July 20, 1998 Slide 5

Consider both the "political" and "economic" differences of global satellites that matter to policy making. Regulation of these systems in multiple jurisdictions means that the US can influence, but not control, the regulatory burdens imposed on the system worldwide. This fact creates substantial investor uncertainty. Investors must anticipate countless regulatory determinations in all parts of the world. (The Commission has confronted this nightmare when faced by potential regulation of wireless networks by local governments.)

Satellites have economic differences, too. Costs tend to be predominantly "fixed" and incurred prior to initiation of service. They are "sunk" and the assets cannot be converted to other uses. They are shared with other countries since the system is global. Cost sharing lowers average costs as the number of countries and subscribers increase. ICO will "sink" about $ 4 billion in capital. Just to amortize the investment and pay back investors will require revenue of a billion a year. That's before paying operating expenses or permitting earnings. This means tremendous "operating leverage"-- the need for large numbers of countries and users to cover sunk costs and a reliance on volume to repay investors for taking risks.

Transaction costs of global systems account for a substantial portion of start-up costs. They arise when acquiring licenses and spectrum in other countries, in getting operating partners, and establishing marketing and distribution channels. They are unique in kind and in magnitude when compared to domestic systems.

Unlike terrestrial systems, which can be built out "market by market" while generating cash from existing plants to finance construction of future plants, satellite space segment investment and many other costs are "indivisible"; they are "all or nothing". Global systems cannot be built a country at a time or a market at a time. The Commission has recognized the importance of permitting licensees to build out systems incrementally, as cash flow and demand conditions warrant, rather than requiring them to be constructed all at once. It considered but did not adopt a requirement that domestic PCS providers must commit to a full build out of all regional and local markets before offering service in any of them and without knowing what particular state and local costs might arise. Global satellite systems must, nevertheless, be substantially constructed in just that way. The space segment must be built all at once and before a single customer can be served or a cent of revenue collected and without knowledge of costs in numerous national jurisdictions.

There are special demand characteristics as well. Economists refer to "consumption externalities". These externalities characterize the sensitivity of economic welfare for US citizens of increasing the number of countries and consumers on the network. Like a telephone system, the more people who are hooked up the more value for each individual user.

## External Costs of US Relocation Decision

- ROW may take US decision as "license"
- ROW has differing policy agenda
- ROW may (mis)apply policy to US-based satellite systems
- Effect may be to export and encourage policies that conflict with US goals

*CompassRose International, Inc.* July 20, 1998 Slide 6

I want to emphasize the notion of "externalities" here in the context of US decisions regarding relocation costs -- the costs to incumbents of making room for new technologies and applications . It is very important for the Commission to consider the external global costs -- not just domestic implications -- of any decision to impose costs on global satellite providers. Just as markets work only when the costs and benefits of decisions are borne by decision makers, world policy leadership can work only when all externalities are recognized. These externalities are important to markets and to world regulatory practices -- a fact made clear by the very existence of the ITU for example. So it is with domestic rulemakings impacting global satellite economics. Regulators in the rest of the world will, as they have in the past, use US precedents as a model. That has been and can be beneficial in some contexts. It can also be harmful, particularly if regulators in the rest of the world use US precedents to adopt policies inconsistent with US goals.

This could happen in a variety of ways. The rest of the world could use the US decisions as "license" to discriminate against US carriers. It can use the US policy as reason to replace aging infrastructure that might otherwise not have been replaced due to funding constraints. In any event, it can place satellite systems in a position of having to pay to get spectrum and market access with little or no negotiating leverage. The rest of the world does not always share the US policy agenda and there is the danger that US precedents will be "misapplied" in pursuit of foreign other national goals. The effect may be to export bad policies.

## How Relocation Costs Matter

- Effects on competition policy
- Effects on investment and innovation policy
- Effects on market access
- Reactions of foreign administrations
- US leadership in satellite development

CompassRose International, Inc. July 20, 1998 Slide 7

Taken in isolation, it has been argued that imposing relocation costs on satellite systems is in the best interest of the public. But, before the Commission acts on that assumption, it is important first to recognize the full range of implications of such a decision.

Imposing additional spectrum-related costs on ICO will handicap it relative to its principal competitors, who are already licensed and have been spared the burden, here and abroad, of any such costs. Differential treatment of competitors in the same market will be regarded as discriminatory and create an unfortunate precedent. This will be a marked departure from the Commission's efforts to "create level playing fields" for new entrants.

This impact on market access will spill over, no doubt, to proceedings in other countries and the foreign reaction, while not specifically predictable, is unlikely to be uniformly congenial to the interests of US carriers or otherwise to advance US policy interests.

The net effect of any relocation cost decision must fully reflect concerns in each of these areas. Immediate and obvious impacts must be considered in the context of distant and collateral ones. The long term potential negative effects on achieving US goals of satellite development should be of considerable concern. Satellites and companion undertakings are major contributors to US growth, technology leadership and macroeconomic welfare.

# Capital Market Effects of Relocation Policy

- Increase expected costs
- Foreign "multiplier" of US relocation burden
- Increase uncertainty
  - Investors asked to underwrite costs from foreign reaction
- Foreign barriers to entry reduce cash flow
  - Cost effects
  - Revenue effects
- Significant costs of delay -- uncertainty and risk

CompassRose International, Inc. July 20, 1998 Slide 8

Let me turn now to a more specific set of concerns about relocation costs and how they matter. In particular, let me turn to how they matter to investors in this risky and capital intensive undertaking.

A US decision to impose relocation costs may well be used by the rest of the world to impose a variety of "tariff-like" or "tax-like" charges on US carriers. This cost "multiplier" can increase satellite costs indirectly by increasing uncertainty and risk, but also directly by increasing "transactions" costs. Foreign entry barriers that may be spawned by US decisions are of great concern to investors who realize that they must reach as large a market as possible if they are to underwrite the considerable risk of the new venture. As ICO prepares to go public with an initial offering, these threats to cash flow plus current prospects for delay in US processes are provoking acute concern and spirited analysis among investors and operating partners alike. Relocation costs translate to substantial additional costs per minute of customer use.

It is said that "Time is money". So it is here -- the costs of delay are compounded. All systems, but one, are go. The technology is there, the markets are there, but, regulatory uncertainty is a troubling source of unknown cost for investors.

What is at stake here is not simply application of a recent precedent established in the PCS proceedings, which I hasten to add represents an entirely different set of facts, so different as to be of little precedential value. (Recall the earlier discussion of political and economic idiosyncrasies of global satellites.) The Commission's decision on relocation charges will have direct impacts not just in terms of "fairness" to incumbents, but will to greater or lesser degrees have negative effects on the Commission's commitment to (1) encourage new technologies and applications (2) reduce barriers to innovation, and (3) encourage investment and risk taking in new technologies generally and in the satellite field in particular.

# Economic Effects of Alternative Relocation Cost Assignment

For Satellites:

- "Substantial" burden

For Broadcasters:

- Negligible effect On:
  - Cash flow; earnings
  - Capital budget
- No Effect On:
  - Consumers
  - Resource allocation
  - Technological change
- Broadcasters will "Go Digital" in any event

CompassRose International, Inc. July 20, 1998 Slide 9

I understand that what is being considered involves substantial payments by ICO to compensate broadcasters and others to relocate. As I have set forth earlier, such payments may be multiplied abroad to the detriment of a variety of US interests. It is instructive to ask what the public gets for this added cost and risk. So far as I have been able to determine -- and I want to emphasize that proponents of relocation have not put much in the way of specifics into the record -- but, so far as I can determine the effect of broadcaster-funded relocation could have negligible, almost undetectable, impacts on cash flow, earnings and annual capital budget expenditures. While it is understandable for broadcasters to want to avoid costs whereever possible, the fact is that the costs to them of relocating are almost inconsequential relative to current cash flow and earnings levels. Investors in the securities of publicly traded broadcast properties would properly regard the charges as "nonevents" -- a term used by analysts to depict matters of little financial or economic consequence.

From a public interest point of view, my analysis indicates that directing broadcasters to pay their own relocation costs would have no detectable effect on consumers, no impact on overall resource allocation or capital committed to the sector and no effect on the rate of technological change. Indeed, broadcasters will no doubt eventually, and relatively soon, be impelled to "GO DIGITAL" without regard to Commission imposed assistance from ICO.

In short, beyond claims of fairness -- which may be invoked by all parties -- there is little economic basis for shifting broadcaster relocation costs to new technologies. Doing so stimulates costs well beyond any benefits claimed.

# Views of "Like" Services

- Technical or spectrum-based view
- Economic view
  - Supply-side view
  - Demand side view
- Past Commission definitions
  - Customer perception: "critical", a "linchpin"
- "Likeness" driven by user perceptions
- Significant competitive effects of different policies for "like" services

CompassRose International, Inc. July 20, 1998 Slide 10

I understand that there is some difference of views among parties, and perhaps staff, regarding what constitutes "like" services for purposes of determining equal regulatory treatment. One point of view is that services making use of the same spectrum or spectrum in the same "band" are like each other and unlike those produced outside the band. That technical or spectrum based view may be useful in some contexts but I believe the correct perspective here is the "demand side" view, based on user perspectives, of what constitutes a like service. Both market analysis and Commission precedent support this view.

One fact is clear. ICO's most direct competitors use spectrum in other bands. To claim that it is fitting either in a policy context, or in terms of basic fairness and lack of discrimination, to impose costs on one firm (ICO) and not its competitors on grounds that they use different frequencies in different bands is to create technical and political distinctions where there are no or inconsequential market differences. ICO, Iridium and Globalstar will compete vigorously in the market place and vie to satisfy similar, and in many cases identical, customer requirements. These companies will produce "like" services when viewed by users or from past Commission perspectives (according to the Commission, customer perception is critical, a linch pin in the determination of likeness.). There are significant potential competitive effects of imposing costs on one competitor that are forgiven for others. To rationalize such regulatory discrimination on the basis that the firms use different bands is to ignore the reality of the marketplace and the substitutability of truly "like" services.

# Summary and Conclusions

- Domestic precedents of limited value
- Relocation costs will be magnified globally
- Time is money; risk; loss of opportunity
- FCC rules will impact:
  - Consumer choice
  - Market share
  - Success in marketplace

CompassRose International, Inc. July 20, 1998 Slide 11

To conclude quickly, I want to emphasize the limited value of precedents established in the context of terrestrial markets that are purely domestic. Global satellite systems involve very different political and economic considerations. Policies, like assignment of responsibility for bearing relocation costs, that have been successful in domestic, terrestrial contexts (like PCS) ought not to be extended without recognition and analysis of the complexities and idiosyncrasies of markets and politics of global satellites. Such costs will be magnified globally but not in predictable amounts or time frames and with considerable additions to risk and uncertainty.

Relocation rules will have significant effects on consumers (who ultimately pay all regulatory costs). They will distort the market's determination of shares going to different competitors and in the long run they will have an important impact on success in the marketplace. These determinations should be left to the market and not unduly prejudiced by regulation.

NUCOMM INC.
MICROWAVE COMMUNICATION PRODUCTS

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FCC MAIL ROOM

February 11, 1998

Ms. Magalie Roman Salas
Secretary
Federal Communications Commission
2000 M. Street, N.W. - Suite 480
Washington, DC 20554

EX PARTE OR LATE FILED

Re: EX PARTE
ET Docket 95-18
RM - 7927
PP - 28

Dear Ms. Roman Salas,

As President of Nucomm, Inc., a microwave equipment manufacturer, I want to bring to your attention the results of recent laboratory and field tests conducted by Nucomm to examine the use of digital microwave technology for the broadcast industry. The study, a copy of which is attached, reviews how the digital video microwave technology can be applied to fixed point-to-point and electronic news gathering ("ENG") systems and consider the trade-offs of digital vs. analog video microwave systems.[1] We wish to submit our study to be included as part of the record in the above noted proceeding.

Recent FCC rulings on HDTV changed the microwave link requirements regarding digital video microwave for broadcast applications. The broadcast industry is increasingly interested in digital video technology as a means of enhancing existing systems and demand for digital video microwave will require the microwave manufacturer to supply new equipment components. Although a wide array of digital products such as digital cameras, editors, storage devices and encoders is available, little has been said about converting the fixed point-to-point studio-to-transmitter link ("STL"), transmitter-to-studio link ("TSL"), intercity relay ("ICR"), and ENG microwave link from analog to digital transmission, a critical part of the total production system.

Nucomm has conducted both laboratory and field test using digital video microwave systems in fixed point-to-point and ENG applications in order to inform TV station engineers about the advantages, disadvantages and trade-offs of digital vs. analog video microwave systems. These test results show that applying digital video to STL and ENG microwave systems can conserve frequency spectrum and yield superior quality and performance equal to or better than analog systems under both fading and multi-path environments.

[1] The study is also available to the public on the internet on our homepage (www.nucomm.com) in the directory Apps Notes.

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We have presented the results of our test at several industry conferences including: the Society of Broadcast Engineers ("SBE") September 26, 1997 meeting/conference in Syracuse, New York; the October 22-24, 1997 SBE conference in Seattle, Washington; and the Society of Motion Picture and Television Engineers ("SMPTE") conference in New York City on November 21-24, 1997.

We also would be happy to present our finding to you if you would find them of interest. Please feel free to call to set up an appointment if you are interested in further details regarding the study.

Sincerely,

John Payne

Dr. John B. Payne, President
Nucomm, Inc.

cc: Secretary Salas
Enclosure

# Digital Video Microwave Systems for STL and ENG Applications & Test Results

By Dr. John B. Payne, President
NUCOMM, Inc.
101 Bilby Rd
Hackettstown, NJ 07840
Ph. 908-852-3700, FAX 908-813-0399
e-mail: john@nucomm.com



NAB97, the FCC ruling on deadlines for HDTV and recent acts by Congress have signaled the dawn of a new era for Digital Video Microwave for broadcast applications including Fixed Point-to-Point (i.e. STL, TSL, ICRS etc.) and ENG in the United States and the world. The manufacturers of the digital CODEC, Multiplexer (MUX) and MODEM equipment have little if any knowledge of the microwave link requirements. Further more they appear to have no interest in integrating these systems. Therefore, the demand of Digital Video Microwave Fixed Point-to-Point and ENG will require the microwave manufacturer to supply part or all of a turnkey package including the transmitting/receiving equipment, CODEC, Multiplexer and MODEM components. This offers an excellent opportunity as well as a challenge for the manufacturers of Digital Microwave equipment to move into a new and expanding market area.

Because of this, it has become increasingly important for TV Station Engineers to know the advantages, disadvantages and tradeoffs of Digital vs. Analog Video Microwave Systems. The purpose of this paper is to:

- Present an overview of how the Digital Video Microwave technology will be applied to STL and ENG systems,
- Present actual laboratory and field results of tests conducted by NUCOMM using Digital Video Microwave Systems in STL and ENG applications.

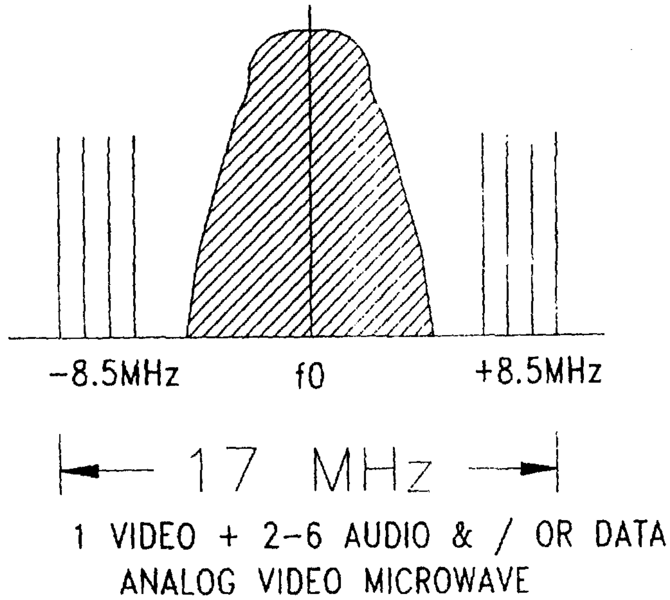
**Conclusions:** Applying digital video to microwave systems for STL and ENG systems can conserve frequency spectrum and yield superior video and audio quality and performance equal to and better than analog systems under both fading and multi-path environments.

## A - Why Digital ?

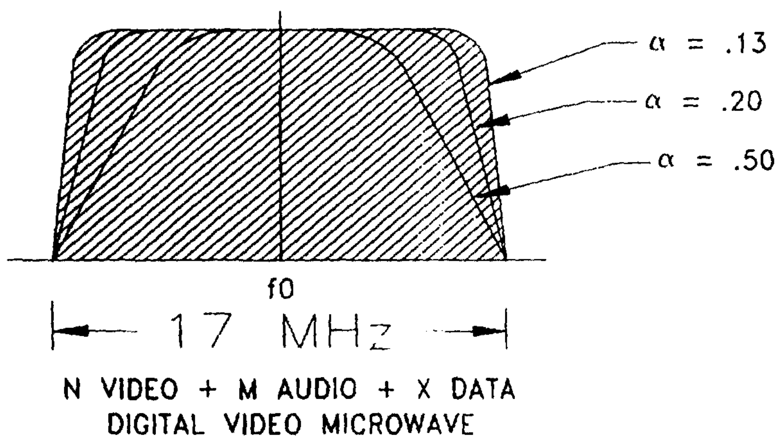
The basic answer to "WHY DIGITAL" is that transmitting in a digital format makes much more efficient use of allocated frequency spectrum. However, another advantage is that of an error-free picture under most conditions. **Frequency spectrum is like land here on earth! No more is being made.** Therefore, we must learn to make the best of what we have. And, what we have is in high demand.

To demonstrate how digital video microwaves can make better use of the allocated bandwidth, refer to the example in Figure 1 below. This shows the spectrum of an analog signal and that of a digital signal. The analog spectrum is for a single video and four audio FM transmitter. Its spectrum falls within a 17 MHz bandwidth such as in the 2 GHz band. All of the empty space within this band that is not occupied by the analog signal can be considered wasted spectrum.

The lower spectrum in Figure 1 is that of a transmitter being phase and amplitude modulated with a digital bit stream. It can be seen that the spectrum is better utilized. Ideally the desired shape would be a perfect rectangle. The closer the spectrum approaches the rectangular shape, the more information can be transmitted in a given bandwidth. It is the RF Digital Modulator that receives the data pulses and converts them to a 70 MHz modulated signal. The Digital Modulator and Demodulator when combined in a single unit are referred to as a MODEM. In




**Spectrum of Analog Modulation**
**(A)**




**Spectrum of Digital Modulation**
**(B)**

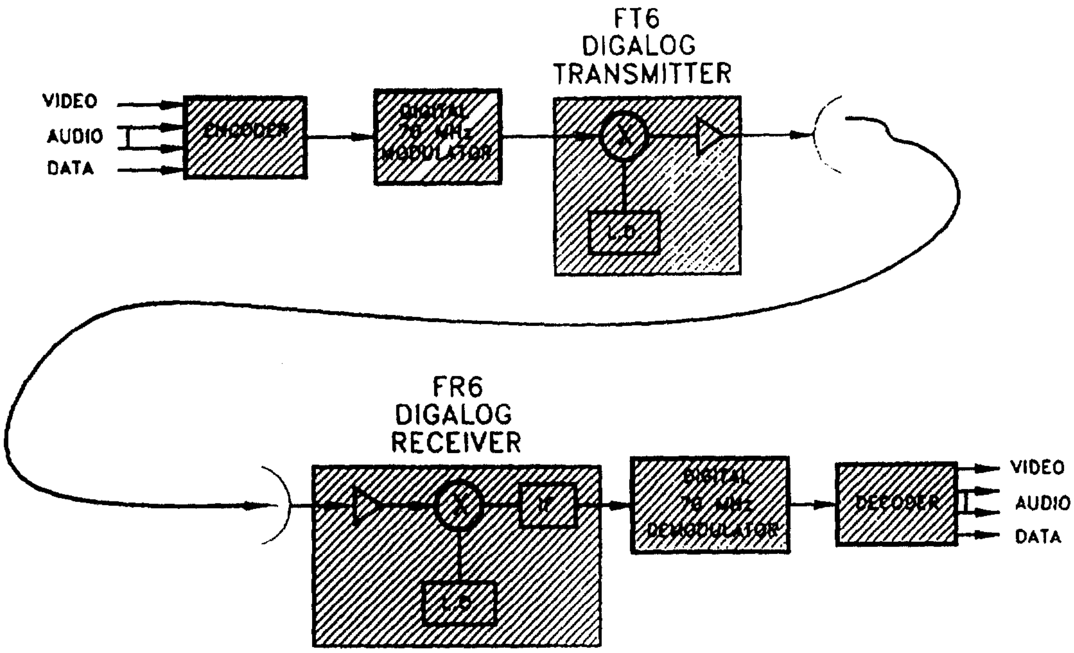
**Spectrum of Analog and Digital Modulation**
**Figure 1**

this paper and for terrestrial microwave we refer to them separately as Digital Modulators and Digital Demodulators since they are generally packaged separately and usually as part of the transmitter and receiver units.

To obtain the desired spectrum shape of Figure 1B, the data pulses that are inputted to the Modulator must be shaped by a low-pass-filter, referred to as a Finite Impulse Filter (FIR), to produce the desired spectrum shape. The parameter that relates the pulse shape to the spectrum shape (which is a function of occupied bandwidth) is the $\alpha$ parameter. The spectrum is shown for three different pulse shaping networks. When $\alpha = .13$ the spectrum is seen to be extremely efficient. Practical values for $\alpha$ range $.13 < \alpha < .50$ with .20 being a typical value.

## B - Digital Video Microwave Architecture:

The modulation and type of microwave radio required to transmit Digital Video information is considerably different from that used for Analog Video transmission. Figure 2 shows a simplified block diagrams of a Digital microwave system for transmission of a single video picture. The modulation process is considerably different from Analog modulation. Here the Video and Audio input signals are first digitized, then compressed and finally combined with the digital Data inputs. The unit that does this digitizing, compressing and combining is referred to as an Encoder. Generally the Encoder adds some Forward Error Correction (FEC). The output from the Encoder is a digital bit stream in either serial or parallel form. The output is generally measured in terms megabits per sec (Mbits/s). The output data rate from the Encoder depends on the amount of compression used and FEC. Typically the output data rate would be in the range of 1.5 to 34 Mbits/s (some applications require rates as high as 45 Mbits/s).




**Single Digital Video Heterodyne System**
**Figure 2**

If a single video, audio data combination is to be transmitted as shown in Figure 2, the Encoder output is directly converted to a 70 MHz RF signal in the Digital Modulator. The modulation used in Digital Modulators typically is QPSK or multiple level PSK or QAM. This type of modulation is considerable more complicated than the FM modulation used in analog radios. Both QPSK and QAM use a combination of phase and amplitude to modulate the 70 MHz carrier.

The 70 MHz QPSK or QAM Digital Modulator output is up-converted (heterodyned) to the RF microwave frequency and amplified in a linear type RF amplifier. The RF microwave signal is sent directly to the antenna or diplexer with other microwave signals.

At the receive end the RF signal is down-converted to 70 MHz and the Digital Demodulator outputs the compressed data stream. The digital data stream is then decoded (uncompressed) in the Decoder to produce the final video, audios and data.



101 Bilby Road, Hackettstown, N.J. 07840 Ph: 908-852-3700 FAX: 908-813-0399

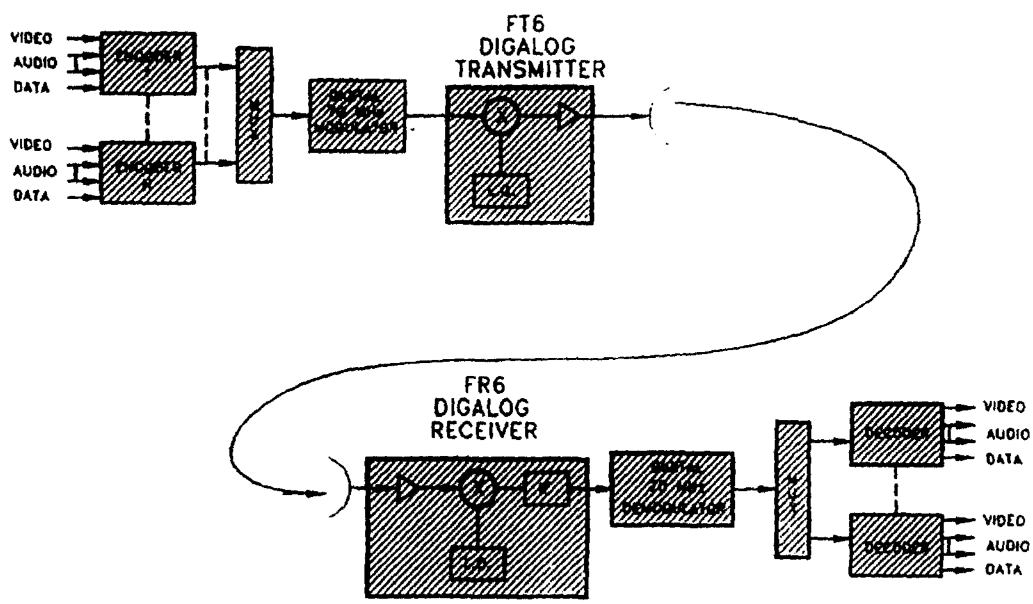
At the receive end, the Digital Demodulator and Decoder components are general combined in a single receiver with the input at 70 MHz or L-band (IRD).

However, depending on the manufacture, the type of compression used (MPEG-2, ETSI or other proprietary compression) and the Encoder output data rate, the demodulator and decoder may require specially designed boxes.

Figure 3 shows a block diagram for combining multiple video, audio and data onto a single microwave carrier. Multiple encoders are used to digitize, compress and combine the inputs from each source. The multiple encoder outputs are combined by a Multiplexer that outputs a digital stream at a rate equal to the sum of the input data streams. That is, if two Encoders output 15 Mbits/s and 10 Mbits/s respectively, then the multiplexer output will be at about 25 Mbits/s.

The multiplexer output data stream is feed to the Digital Modulator that in turn converts the data from the Multiplexer to a QPSK or QAM phase and amplitude modulated 70 MHz signal. The microwave heterodyne transmitter up-converts the 70 MHz to the desired operating frequency.

Typically, the digital components on the transmitter end take on the form shown in Figure 3. However, some manufactures integrate the Encoder, Multiplexer and 70 MHz Modulator into a single piece of equipment.



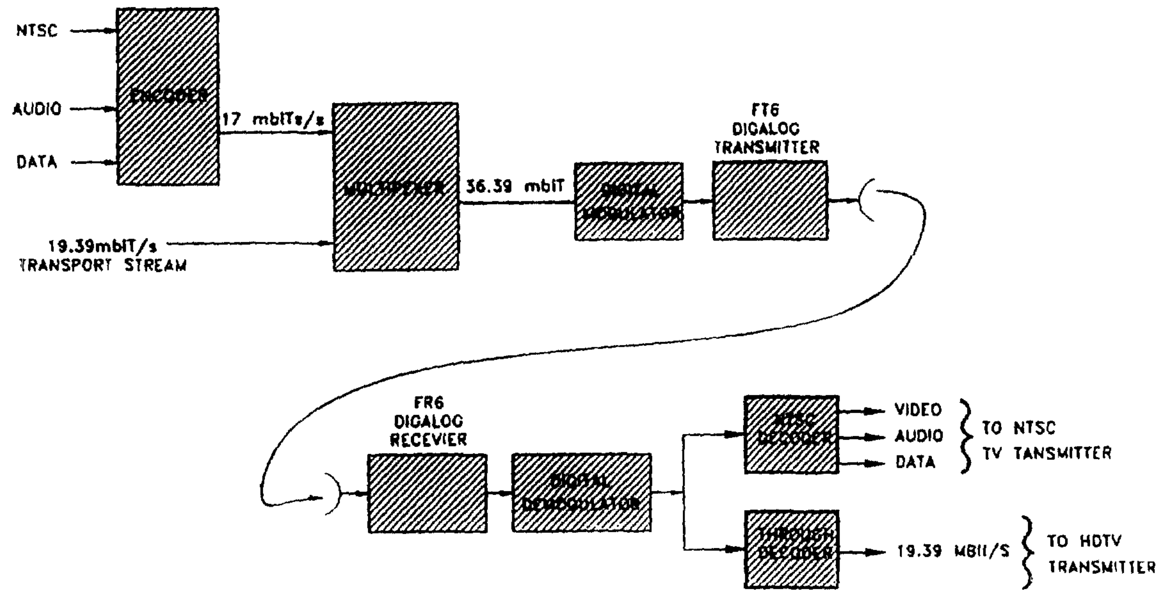

**Multiple Digital Video Heterodyne System**
**Figure 3**

At the receiver end the microwave signal is down-converted and demodulated. The multiple encoded data is divided into multiple channels by the Demultiplexer before being decoded in individual Decoders. Often but not always, the demodulator, demultiplexer and decoding are done in a single, less expensive Integrated Receiver Decoder (IRD).

It must be remembered that digital encoding and decoding technology is still evolving with standards still being modified or just being proposed. Today's prices will come down considerably over time as standards are established and competition increases. Today there are at least 10 manufacturers of digital encoders and decoders. There are many more that are just starting development. Competition will be very strong in the coming years.

## C - NTSC and HDTV Dual Channel STL:

Figure 4 shows how the NTSC and the HDTV transport stream can be simultaneously transmitted from the studio to the transmitter, over a single microwave link. The NTSC (or PAL-B/G) composite signal is digitized and compressed to the desired output rate, ie, 15-25 Mbits/s. This is combined with the 19.39 Mbits/s (or 45 Mbits/s) HDTV transport stream to yield an input Data rate to the Digital Modulator of 34.4 for the 15 Mbit/s encoder output (44.4 Mbits/s for 25 Mbits/s encoder output). Using a QPSK Modulator the bandwidth required to transmit the 34.4 Mbits/s is about 22 MHz. Using 16QAM the bandwidth is reduced to 11 MHz. and 30 MHz, which would be adequate for 7 or 13 GHz. For higher NTSC data rates or operation a 2 GHz, 8PSK or 16 QAM would be required.




**Dual Channel Digital Video STL for NTSC and HDTV**
**Figure 4**

On the receiver end, the received signal is demodulators and applied to two Decoders. The NTSC Decoder outputs the composite and audio signal to be applied to the NTSC transmitter. The other Decoder acts as Demultiplexer and passes the HDTV transport stream through to the HDTV transmitter. NUCOMM offers a complete turnkey system for this application.

## D - DIGALOG - Digital & Analog Microwave System:

To meet the broadcasters immediate need for continued transmission of analog signals today but to be ready for the coming transition to digital, NUCOMM has developed the DIGALOG FT6/FR6 Radio system. The DIGALOG Radio operates as an analog radio today but is configured for digital operation tomorrow. Figure 5 shows a block diagram of the DIGALOG FT6 transmitter that can operate in both Analog and Digital modes. The Analog Modulator is supplied for analog operation. The Digital/Analog power amplifier is operated in its Analog mode for maximum power output. When the user is ready to go digital, the Digital Modulator can be added to the same two rack high unit. A single switch on the inside of the front panel switches the power amplifier to its Digital mode.

Figure 6 shows a block diagram of the DIGALOG FR6 Analog/Digital microwave receiver. The receiver is supplied with an analog demodulator for analog operation. A digital demodulator can be installed at a later time. Two IF bandwidths, 30 and 45 MHz, are provided in the IF amplifier. The 30 MHz bandwidth filter is to be used for analog or low data rate digital operation. For data rates of 45 Mbits/s or higher, the 45 MHz bandwidth filter is switched in.



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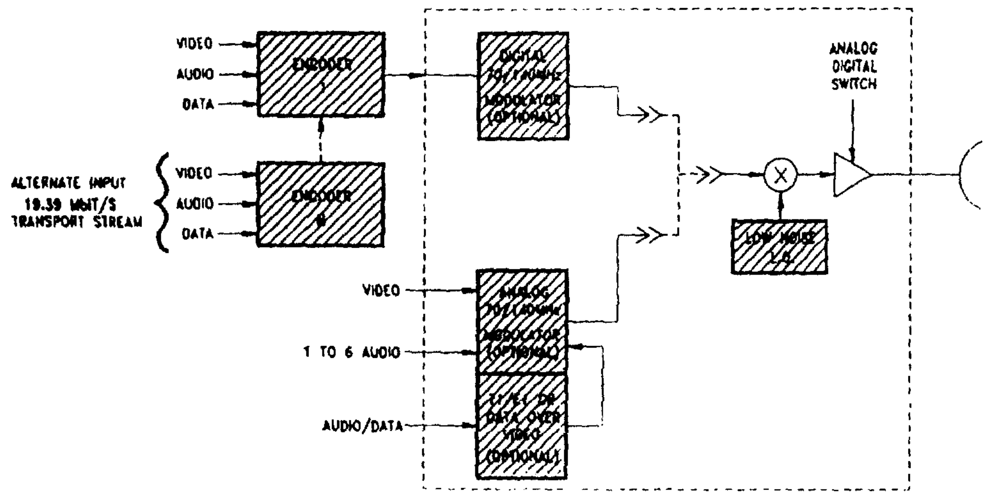
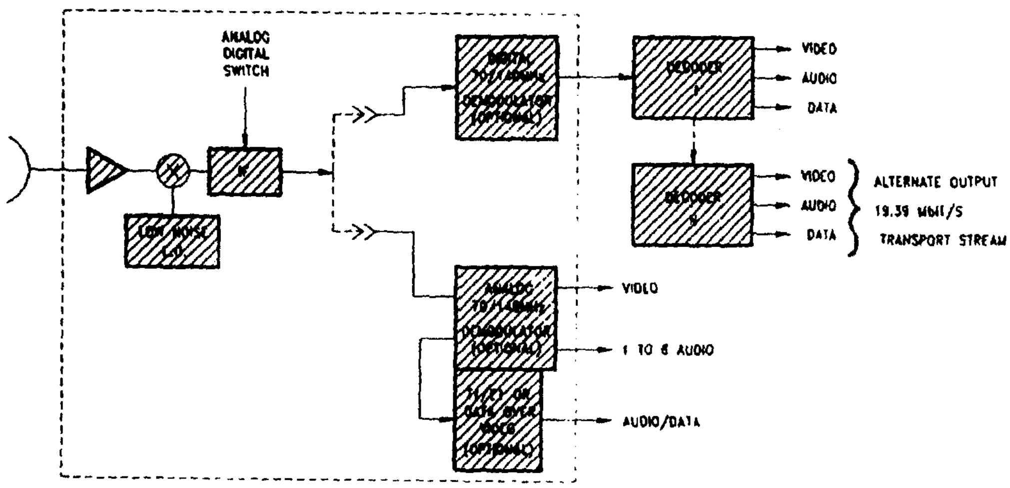
DIGALOG-FT6
ANALOG/DIGITAL
TRANSMITTER




**DIGALOG FT6**
**Analog/Digital Microwave Transmitter**
**Figure 5**

NUCOMM DIGALOG-RX6
ANALOG/DIGITAL
RECEIVER




**DIGALOG FR6**
**Analog/Digital Microwave Receiver**
**Figure 6**



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## E - DATA RATE verses BANDWIDTH of a Digital Video Microwave System:

Equation 1.1 below defines the Bandwidth required to transmit a bit stream of a given data rate. The shape of the transmitted spectrum will like that shown in Figure 1B. The transmitted bandwidth is a function of input Data Rate (Za), Modulation Coding (M) for such methods as QPSK, 8PSK and 16QAM, Forward Error Correction and the Spectrum Shape Factor ($\alpha$).

$$\text{Bandwidth} = \frac{(1+\alpha)\sum Z_a \text{ Mbits/sec}}{FEC * M} \qquad (1.1)$$

where $\sum Z_a$ = Sum of Data Rates from one or multiple Encoders in Mbits/sec.

FEC = VC * RS

FEC = Forward error correction ; If no FEC is used, then FEC=1

VC = Viterbi Coding: Typical 1/2, 2/3, 5/6, 3/4, 7/8and

RS = Reed-Solomon: Typical 188/204, 192/208.

M = 2, 3, 4, 5, 6, 7, 8 :Coding level of the Modulator ; see TABLE 1.

$\alpha$ = Spectral Shaping Factor.

Table 1 gives the values for M, the Modulation Coding, for common forms of modulation used in digital systems. Also given is the bit efficiency, in Bits/Hz/s, for each form of modulation for a typical $\alpha = 0.2$. Note that as M increases, the required bandwidth to transmit a given data rate decreases by the Bits/Hz/s number (assuming FEC=1). Also, as the Modulation Coding number M increases, the required received carrier-to-noise (C/N) level must increase for a given Bit Error Rate. This is the price we must pay for better transmission efficiency. The C/N for each M is given for a normalized C/N power ratio corresponding to a BER of $1X10^{-6}$.

**Table 1**
**Types of Modulation**

| TYPE OF MOD. | M | Bits/Hz/s $\frac{M}{(1+\alpha)}$ | C/N (dB) |
|---|---|---|---|
| PSK | 1 | .833 | 10 |
| QPSK | 2 | 1.66 | 10 |
| 8PSK | 3 | 2.50 | 14 |
| 16QAM | 4 | 3.33 | 17 |
| 64QAM | 6 | 5.00 | 23 |
| 256QAM | 8 | 6.66 | 28 |

Notes: 1-Normalized carrier-to-noise power ratio corresponds to a BER of $1X10^{-6}$.
2-Assumes No Error Correction
3-Assumes $\alpha = .20$

The most robust and common form of digital modulation is QPSK. From Table 1, it can be seen that this will result in a bandwidth reduction of 1.66. In many cases more bandwidth reduction may be required such as 3.33 for 16QAM or 5.0 for 64QAM. As the coding number increases, the signal will become much more susceptible to RF interference, multi-path effects, etc. Also the system gain decreases substantially due to lower available output power and the requirement for higher receive carrier levels for a given bit error rate.

In an STL link where strong signal levels are the norm but picture quality and link reliability are important, the higher forms of modulation can usually be justified. However, in ENG links where multi-path and weak signals are the norm QPSK would be the recommended form of modulation. Generally in ENG operations, getting the picture through is of higher priority than picture quality, therefore QPSK is recommended. To fit the Digital Video data rate within the allocated bandwidth, the Encoder data rate only needs to be reduced and the FEC adjusted to obtain a reliable picture. Reducing the data rate with today's Encoders has little effect on the picture quality as will be shown from the test results given at the end



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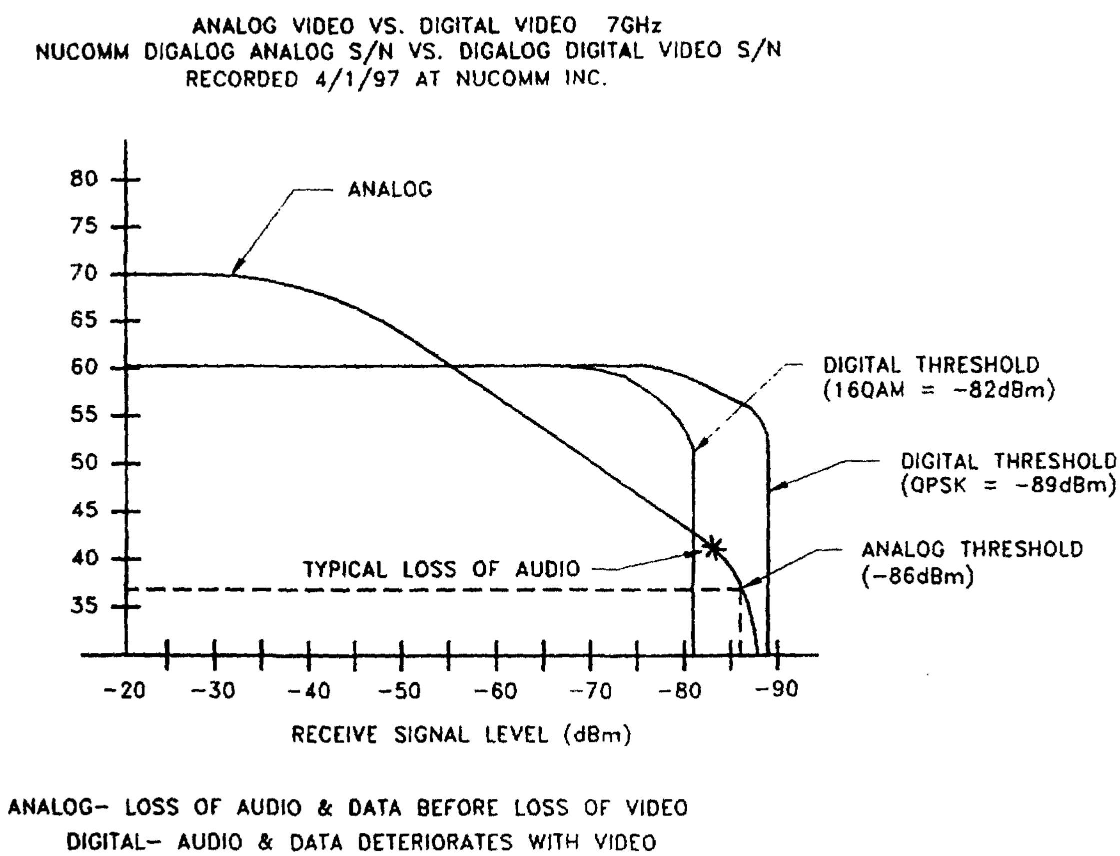
of this paper. Therefore, it becomes a judgment call on the part of the ENG management whether to give up some picture quality for a reduced bandwidth. There may be no other option as the 2 GHz allocated bandwidths are further reduced by the FCC.

## F - Typical Analog vs. Digital Performance:

Figure 7 shows the performance of an Analog link and a comparable Digital link (as shown in Figure 2, 3 or 4). The Analog link shows a video S/N of 70 dB for high receiver input signal levels. As the signal level drops, the video S/N will begin to drop in a linear relationship to the input signal level. When the receiver threshold is reached (typically -85 dBm at 7 GHz in today's video receivers), the video S/N drops much more rapidly than the receiver input signal level. In a typical analog system, threshold is defined when the video S/N reaches -37 dB. At a receive level of about -82 dBm the audio channels will become very noisy and unusable.



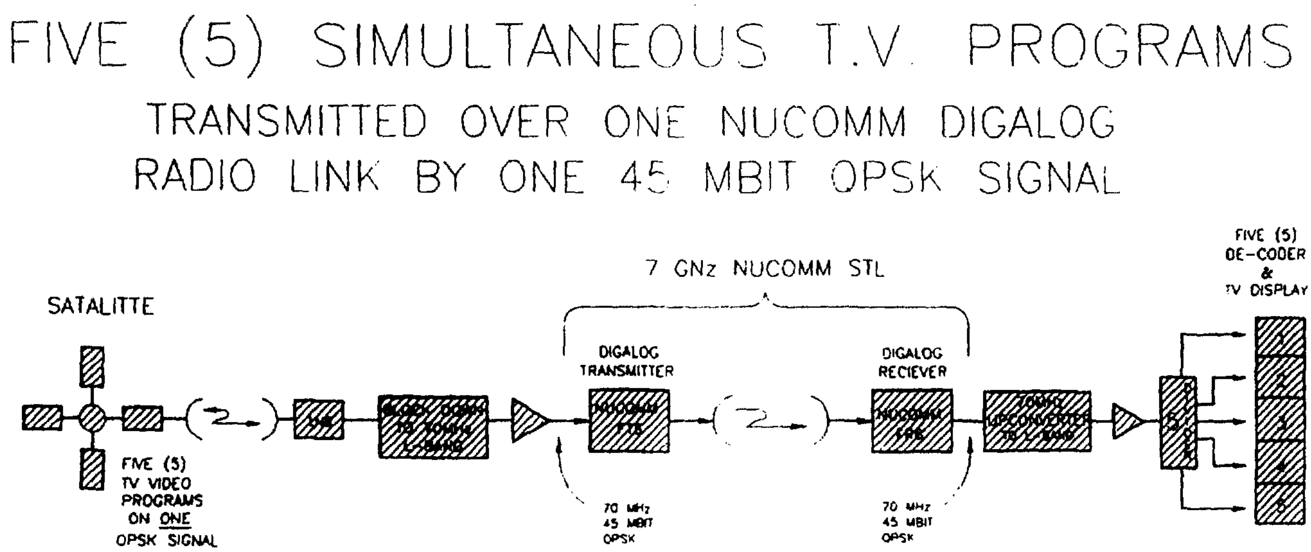

**Video S/N Verses Receiver Signal Level**
**for Analog & Digital Systems**
**Figure 7**

The Digital link shows a lower video S/N than the Analog link for strong receive signal levels. This lower S/N is due to quantizing errors in the digitizing of the video signal in the Encoder. Typically, a 10 bit digitizer will give a video S/N of about 60 dB. The advantage of the digital system is seen as the input signal level is reduced, the video S/N remains constant at 60 dB. This S/N will be maintained until the error correcting can no longer handle the error. The system then crashes. The result is that the video picture freezes. The point at which the S/N "fall off the cliff" is generally at or below the analog threshold point. This "fall off the cliff" point depends primarily on the amount of error correction that is built into the Encoder and/or the Modulator and the type of modulation used.

NUCOMM passed a 45 Mbit-QPSK digital signal with error correction through the NUCOMM 7 GHz FT6/FR6 DIGALOG (Analog/Digital) transmitter and receiver, the cliff point was 4 dB below (-89 dBm) the system's analog threshold. An additional advantage is that the audio and data channels remain at a high S/N level until the cliff point is reached. Using 16QAM, the digital threshold is worse than the analog threshold by 3dB. This 7dB reduction in threshold by using 16QAM instead of QPSK (as shown in TABLE 1) has enabled us to transmit twice the data rate within the same bandwidth.

## G - STL/Line of Sight Experimental Results:

NUCOMM tested a Digital Video Microwave System setup as shown in Figure 8. A 45Mbit QPSK signal carrying five video programs plus one audio per video was down-linked from a USSB satellite. This signal was first down-converted to 70 MHz. The 70 MHz signal was inputted to a NUCOMM 7 GHz DIGALOG radio operating in the Digital mode. The output of the transmitter was attenuated through a variable attenuater so as to reduce the signal level at the receiver input to well below the receiver threshold. The receiver's 70 MHz output was upconverted to L-band and fed to five satellite receivers. The output of each satellite receiver was displayed on a color monitor. The satellite receivers have a built in bit error rate counter that displays the BER as signal strength. A signal strength reading of 100 means that there are no errors being detected. A reading of 10 means that there are many errors. Below this level the system crashes. Figure 9 below shows the result measured using a VM700 to measure the video signal-to-noise and the built-in signal strength BER indicator to show how the bit errors change with the microwave receiver signal strength. The Analog threshold of the system in the Analog mode was measured at -85 dBm. Note that the Digital threshold or "Cliff" point is at -89 dBm. That is 4 dB better than in the Analog mode. Just as important is the fact that all five video pictures and audio sound remained perfect until the "Cliff" point was reached. The difference in signal level between a perfect picture and a frozen picture was 1 dB.




**Test Setup for Measuring Digital Video Performance**
**Figure 8**



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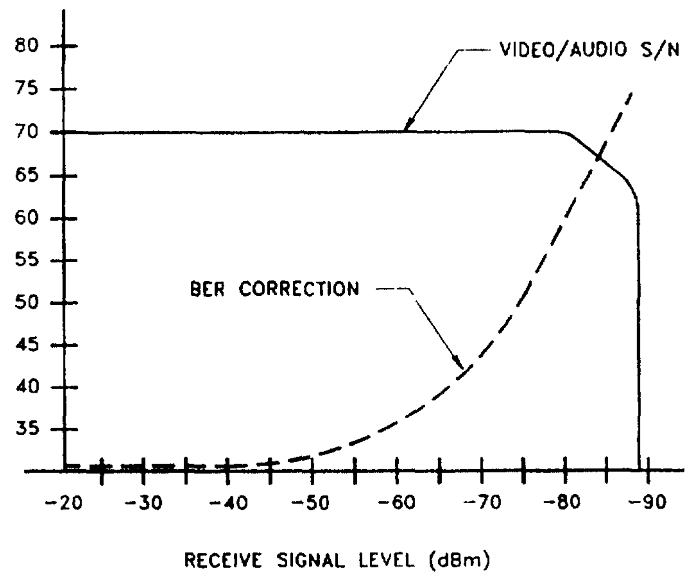


**Test Results from Experimental Test Setup**
**Figure 9**



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